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The Application of Energy Absorbing Structures on Side Impact Protection Systems

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Abstract: This paper presents a system to improve the protection to the occupants of a World Rally Championship Car in case of a side impact involving a tree collision using energy absorbing structures. An outline of the immediate events after the car crash into a tree are provided followed by an analysis of a typical standard rollcage, then the design criteria and features of a carefully selected design concept. The design model is produced using solid modelling/I-DEAS 11 softwares and PAM-Crash is used for the simulations. The simulation results show side impact protection system is capable of absorbing and dissipating 98% of the energy of a 14 m/s impact involving a 0.2 m diameter tree.

Keywords: Side Impact Protection, Racing Car, Energy Absorption, Sandwich Composites, Structures

1. Introduction

Side impact accidents may result in severe injuries to the vehicle occupants. Most side impacts can be classified into two types, car-to-broad-object and car-to-narrow-object. The larger intrusion caused by the latter type of side impact is generally more dangerous to the occupants. Examples of narrow objects involved in side impacts are trees, poles, lamp posts, and barrier tubes.

In road cars (passenger cars) for instance, side impacts are frequent and often result in extremely harmful crashes (Fildes et al., 2003; Fildes, 2005). Global accident statistics show that side impacts account for approximately 30% of all impacts and 35% of total fatalities (source: German In Depth Accident Study-GIDAS, National Automotive Sampling System-NASS & BMW accident database) (McNeill and Haberl, 2005). Side impacts also require more attention in that there is considerably less crash zone for absorbing energy in the side of the cars compared to the front and rear structures (Strother et al.,), and consequently the occupants sit almost within the crash zone, which often results in severe injuries (Wang et al., 2005).
Rallying cars are susceptible to side impact during the rally. The potential for a high speed collision is more present in rally racing than any other race series since the are no protective barriers or 'off area', such as sand traps, to dissipate the kinetic energy of the vehicle before it impacts a rigid object. In particular, the region around the front door of the vehicle is subject to large deflections into the driving personnel's space during side impact by a cylindrical shaped object such as trees or telegraph poles. For this reason, the side impact velocities in rally racing are significantly more dangerous than in most series and most regulative crash test speeds are too slow for rallying applications. And although, the *Fédération Internationale de l'Automobile* (FIA) has brought forward a variety of safety systems in the WRC

cars, research and development into minimizing structure intrusions during side impacts of racing cars is essential to reduce the effects of side impacts.
In that respect, it is therefore necessary to produce a standard ‘worse case scenario’ design criteria that a design can be produced for and attempt to reduce the risk of injury to the occupants. Unfortunately, published works on side impact on racing cars are very rare as such investigation results are often considered classified and strictly held within the rallying teams’ tight jurisdiction. To the authors best of knowledge, the only detailed works available in the open literature are that of Browne et al. (Browne et al., 1997) on Indianapolis NASCAR type cars and Bisagni et al. (Bisagni et al., 2005) and Savage (Savage, 2009; Savage et al., 2004) energy absorbers for Formula One side impact. Though importantly relevant, both of these studies are not on rallying cars. On the road cars, however, much research has focused on the development of countermeasures including the vehicle side structure energy absorption (Patberg et al., 1998) and human response (Ruan et al., 1991; Farmer et al., 1997) in side impact events. New composite materials (Strother et al.,) and structure optimization (Sparke and Nelson, 2002; Sinha et al., 2007; Zhang et al., 2007) have been widely used and some advanced methods have been developed to protect the occupants during side impact accidents (Lozzi, 1981). Other studies have been inspired by possibility of weight reduction automotive structures by use of carbon fibre-reinforced composites (CFRP) on door structures which can contribute to improve mileage and then to reduce carbon dioxide (Zhang et al., 2007) (Aoki et al., 2007). Tests and simulations similar to frontal impact safety tests (Aekbote et al., ; Yoganandan and Pintar, 2005) are performed to evaluate a vehicle's side impact safety. Various side impact test methods exist (Winlkelbauer, 2004), and the moving deformable barrier with pole side impact test are being used as the standard certified test on a car for side impact safety analysis.
However, racing cars are very different from road cars and some of these systems are either not allowed in the rallying cars (e.g. airbags) or would need a careful re-thinking for practical implementation in a racing car. It is therefore rather unfortunate that little attention has been focused to side impact on WRC rallying cars involving a tree collision.

Presently, the FIA regulates the homologation of rally cars and also provides guidelines on the safety systems that are required FIA Regulations (FIA, 2007). The FIA regulations state that the rollcage must be able to support two static load cases both designed to ensure that the cage could withstand a roll over accident. In principle, rollcage design requirements are laid out so that if a car complies with these regulations it does not have to pass any safety tests. If the rollcage does not meet these design requirements then it must pass a static load test.

One concept being pursued that is likely to offer possible solution to side impact is the use of energy absorbing structures on the WRC car doors. The design presented here appreciates that the cockpit of a WRC car is a relatively complex working environment, and that any design that cause significant distraction from this would likely receive negative feedback from both the drivers and regulators concerned. Nevertheless, in order to implement the proposed design, changes would have to be made to the current FIA regulations for WRC cars. The proposed changes have been kept to a minimum, would be easy to implement and the external appearance of the vehicle would remain unaffected. This paper reports some of the initial studies towards provision of safer side impact protection system (SIPS). A brief discussion is first given on the sequence of events that happens when the car crash into a tree and the likely consequences. The standard cage is then analysed, evolving into design criteria and the design features of the current concept. Modelling and simulation results are given, discussed and conclusions drawn.

2. Crash sequences

One of the major causes of injury in a side impact is the lateral impact on the occupant by the door interior. The severity of occupant injuries in the side impact depends on the manner in which the occupant is loaded and the force deflection characteristics of the interior. In a side impact situation, the sequence of events is as follows: (i) the vehicle collides with an object (in this case a tree) which impacts on the door including the deformation of the door interior as a result of the collision; (ii) the interior of the door hits the driver or passenger, which results in the deformation of the door interior; and (iii) the internal organs of the occupant hitting his/her internal bone and/or vehicle structure quickly follow this.

Prior to the accident, the vehicle, the occupant and their organs are all travelling at the same speed. However, because they are not rigidly attached to each other, they move independently when large G-forces are applied (Melvin and Foster, 2002). Firstly, the vehicle slows down, but the driver continues at the same speed until he/she comes into contact with some part of the car. Their organs doing exactly the same thing albeit on a smaller scale follow. This relative speed can be dangerous. When the driver hits the object (tree, rock, vehicle, etc), the injuries could range from mere bruising, through creating minor open wounds to the breaking of bones. When the occupant's internal organs hit the stationary skeleton, more major injuries can be inflicted ranging from hernias, embolisms, long-term disability, to (the extreme) immediate death. The most susceptible internal organs are located in the head and torso; it is these areas, which are unfortunately the least protected by the body.

3. Standard rollcage

The way the car's side intrudes into the cabin during side impact and the influence of other load paths into the car have been shown to be the major injury determinants rather than simply the extent of the intrusion or side intrusion velocity, as noted by Byard (Byard, 1992). As opposed to a frontal impact, essentially there is no deformation area to absorb the energy of the shock in a side impact. Therefore, the protection relies on a reinforced compartment structure and on the inside of the compartment, especially the door panels. The principle behind this idea is that the door absorbs some of the energy and the rest of it is transmitted through the side impact beams to the safety cell surrounding the passengers, thus reducing the risk of the door intruding into the cabin.

In order to understand what would happen to the rollcage doorbars (Figure 1) in the event of a side impact an analysis of the load paths in the loaded cage was conducted. During a side impact, the steel doorbars are initially loaded out-of-plane and plastic hinges quickly form around the centre area. As the pole intrudes further into the car, the loading on the doorbars members' change to axial with some increased plastic rotation around the impact surface in the welded area. Finally a plastic hinge forms in the upper doorbar where it meets the A-pillar reinforcement member. The fact that the lateral rollbar is one of the stronger members and is supported by many of the elements of the complete structure means that the drivers' feet which have been unrestrained, i.e. where the rollcage would normally be mounted in the car, observes very little deflection if any. The doorbars, therefore, absorb significant impact loading. The magnitude of the energy absorbed by the deflection of the doorbars is less than half that absorbed in the B-pillar. The high rate of absorption for both A- and B-pillar linearly increases with deflection. Thus, the deceleration rate is quite high at larger deflections; a decrease in deflection will therefore resolve into decrease in decelerations. The doorbars will also, in large deflections, enter the passenger compartment in the driver's leg area and the position of the impacted pole will be near the driver's arms. In summary, it can be shown that crashworthiness is good in a B-pillar impact but door bar impact will result in high deflection and low energy absorption and therefore provides the greatest area for improvement.

4. Design of the safety system

4.1 Design Requirements

The following initial targets are seen appropriate for this task: (i) the system is to supplement the protective rollcage required by the FIA WRC Sporting Regulations, and must not interfere with it; (ii) the system should be adaptable to any WRC car. The Subaru Impreza WRC car will be used as a test platform for initial development; (iii) the system should be lightweight and cost effective; (iv) other than an increase in weight, the system should not affect the handling capabilities or performance of the car, and must not interfere with the ability of the driver to control the car; (v) the FIA WRC Sporting Regulations can be modified if required to improve the safety of the occupants; (vi) the system must not increase the time required for the occupants to evacuate the car under emergency conditions, and lastly, (vii) the system must protect the occupants of a 1400kg WRC car, travelling at 50km/h, in the event of an impact against a rigid post of 0.2 m diameter, hit in the longitudinal centre of the front door. The SIPS presented fulfils two set objectives i.e. maximising the amount of energy that can be dissipated in the maximum volume available, and increasing the structural stiffness of the car's side structures susceptible to side impact. The final design should therefore meet three design criteria i.e. the system should: (i) offer protection at any angle of impact; (ii) be capable of withstanding impact load without falling apart; and (iii) have sufficiently low collapse force so that the peak load before crushing does not damage the rollcage and harm the occupants.

As per the WRC Regulations, rollcage modification is fairly limited. Therefore, in order to ensure that the designed system supplement and not interfere with the protective rollcage required by the sporting regulations, the proposed design focus around redesigning the driver and passenger doors. By using energy absorbing materials in the door, energy arising due to the impact could be absorbed. In addition, the extra load is eventually transferred to the rollcage thus reduced, and the rollcage damage tolerance enhanced. An added advantage of this design is the fact that more impact energy may be absorbed by density increase of the filler material.

4.2 Design features

The inside part of the door is completely replaced by the SIPS, which consists of four main components, the Honeycomb Core, Outer Skin, Support Plate, and Support Beam. A representation of the system is shown in Figure 2. Aluminium honeycomb core is used because of its high specific energy absorption capability. The outer side of the core is shaped to match the curvature of the door skin, to maximise the volume of honeycomb that can be fitted. In order to maximise the amount of energy dissipation by the honeycomb core, the Outer Skin is made up of a combination of aramid and carbon fibre-reinforced composite (AFRP/CFRP) with variable ply orientations. The part (Outer Skin) is used to maximise the load per unit area, and therefore must combine stiffness and strength such that it is able to distribute the load over a larger proportion of the Honeycomb Core. The AFRP helps in keeping the skin intact while allowing deformation such that the Honeycomb Core experiences even load distribution during the impact period.

The Support Plate is a sandwich composite constructed from CFRP and an aluminium honeycomb core, allowing high strength yields and relatively low weight construction. The primary purpose of Support Plate is to provide a backing plate to react the forces from the Honeycomb Core during an impact. This in turn allows Honeycomb Core to crush and dissipate energy. As such, Support Plate must be stiff enough to support the maximum forces imposed on it by Honeycomb Core. During a side impact, the plate reacts against the doorbars, distributing the load over their length, and transferring the load onto the main and front hoops of the rollcage. The plate's top is supported against the Support Beam, which transfer the loads onto the main and front hoops of the rollcage. Once the honeycomb is fully compressed, the plate becomes purely a load spreader over the side impact bars. Under these conditions the plate increases the stiffness of the bars, and helps them transfer the load onto the main and front hoops of the rollcage. The Support Plate also distributes the impact loads onto the rollcage bars. However, without appropriate support at the top of the plate, it would be unable to take this role efficiently. Therefore, the Support Beam is added to allow loads transfer from top of the plate to the rollcage tubes. Structurally, the Support Beam is a separate entity from the Support Plate, and complements the plates. For ease of fabrication, the Support Beam and the Support Plate may be manufactured as a single assembly. As with the plate, the beam is made up of aluminium honeycomb core and CFRP skins. Towards the front of the car, the beam has a semi-circular notch that locates over a vertical tube on the cage. This tube transfers the loads from the beam on to the front side of the cage. At the rear, the beam slides into a notch in the B-pillar. An additional vertical bar is welded to the rollcage behind the B-pillar, and the beam transfer loads onto the cage through this bar. The beam must be strong enough to support the maximum load exerted on it by the support plate while the honeycomb core is being compressed. Once the honeycomb core is fully compressed, the beam enhances the stiffness of the car side structure to stop external objects, such as a tree, from entering the occupant compartment.

4.3 Modifications required on the car to implement the design

The relationship of the rollcage tubes and the top of the door in the current car is such that the Support Beam cannot be supported against the rollcage tubes, which is required for the beam to be able to transfer loads onto the cage. Two short tubes need to be added to the cage, so the beam can transfer loads onto the cage. The front tube is added between the A-pillar tube and the top door-bar, as shown in Figure 3(a).

This tube must be welded with its longitudinal axis perpendicular to the floor of the car, and will support the front of the Support Beam. The rear tube, shown in Figure 3(b), is welded between the vertical bar behind the B-pillar and the top side-impact bar, right behind the B-pillar. The pillar must be modified such that the tube is inserted in the pillar, and welded on both sides to its inner skin. This provides adequate support for the rear of the beam. Further, the bottom of the plate needs to be supported so that it can react the loads applied to it. An L-shaped support is welded onto the sill to provide the support area. As can be seen in Figure 3(c), the support is triangulated to provide the appropriate support.

To minimise the intrusion of the system into the escape area for the occupants, the rear support for the Support Beam is positioned behind the B-pillar. However, the space between the outer skin of the B-pillar and the outer side of the door is too small to insert a load-bearing device with enough volume to support the required loads. As such, a notch is cut on the outer skin of the B-pillar for the beam to slide into. The tube added to the rollcage supports the beam and notching the B-pillar does not compromise the effectiveness of the system. This is because the integrity of the B-pillar itself is recovered by welding the tube to the inside wall of the B-pillar, effectively replacing the cut out on the pillar. This notch is covered when the door is closed, thus not interfering with the external appearance of the vehicle. Since the inside part of the door is completely filled with honeycomb, the standard internal handle for the door latch mechanism is rendered unusable. Thus, the rods for the handle are replaced by a cable, which may be pulled to open the door. The cable can be attached to the standard handle, or a custom handle can be made. During an impact, the loads will be transferred from the Honeycomb Core to the Support Plate, and then in to the side impact bars, causing shear stress on the welds that attach the side impact bars to the main and front roll hoops. It is recommended to strengthen these welds by adding gussets between them and the adjacent tubes.

The use of honeycomb core does not leave any space for the window mechanism, and a new way of holding the window in place is required. Hence, the window is bonded to a thin piece of aluminium sheet (top-hat channel), which is inserted into a matching slot machined onto the top of the energy absorption system, and then bolted in place. Aluminium blocks with threaded holes hold the bolts in place. Holes are also machined onto the energy absorption system to accept the aluminium blocks. The blocks are bonded to the energy absorption system, and a layer of CFRP is bonded over them to provide additional support. Figure 4 shows an exploded view of the window installation. This installation allows easy removal and replacement of the window should it get damaged.

Like the Support Beam, the backing plate structure (plate immediate next to the doorbars) takes the form of a CFRP-honeycomb core sandwich panel. As with the Support Plate, this panel may be manufactured as a joint component with the Support Beam, and as such the honeycomb featured would be of the same specification for both sections. Since the function of the backing plate is to support the compression of the energy absorbing honeycomb core, the loading criterion slightly differs from that used in the Support Beam, as well as the support structure. However, the backing plate structure is also loaded in bending when the honeycomb core is impacted. The plate needs to have sufficient stiffness to be able to react this loading, and as a result a composite sandwich structure is again used. The cross ('X') doorbars, as shown in Figure 1, effectively supports the beam. Part of the honeycomb core used to back this plate is shaped so that it covers the diagonal bars, reducing the contact area at the supports.

5. Modelling

Solid modelling/I-DEAS 11 were used to produce 3D models of the design components. The required meshes to perform the dynamic FEA and PAM-Crash simulations were generated in I-DEAS 11 (Figure 5). In general, 8-noded brick and 4-noded shell elements were used in a mapped mesh. In particular, the CFRP parts were modelled as a skin and meshed using 2D-mapped shell elements.

The CFRP properties, lay-up and thickness were then given and varied. A combination of a plain-weave T-300 3k and T-500 12k were used to prepare epoxy-CFRP. The specific ply orientations are withheld due to the sensitivity of the specific racing car/team involved. Solid models of the honeycomb cores (129.75 kg/m^3) were utilised. A representation of a tree was, just like the CFRP parts, modelled as a surface and meshed using thin 2D shell elements. The tree can be modelled as a shell because it is set as a rigid body without any material properties in PAM-Crash. The generated mesh was made relatively coarse in order to strike an acceptable compromise between computation time and accuracy, since the CPU time in PAM-Crash is dependant on the smallest element in the model. To simplify the model and keep CPU time to a minimum, the tree was impacted into the car, as opposed to reality where the car would impact the tree. Therefore the mass and the initial velocity of the car were assigned to the tree to give it the same amount of kinetic energy the car would have at the defined impact conditions. A mass of 1400 kg and the initial velocity of 14 m/s were added to the centre of gravity node of the tree to conduct the simulation.

Firstly, a 'self-impacting interface' was created between the tree and the composite (Outer Skin of the design concept) covering the honeycomb core. To make the side impact protection system react against these supports, a self-impacting contact interface is used between the CFRP shell and the cage/body. A self-impacting contact surface is also created between the CFRP layer of the sandwich backing plate, and also between the inner part of the honeycomb core in the sandwich backing plate. The fourth self-impacting contact interface in the model was set up between the upper and lower tubes of the rollcage and the tree. This was performed such that the tree impacted the cage after the side impact protection system had been fully crushed. The CFRP and honeycomb core parts are 'bonded' together in the model using the so-called 'Tied Interfaces'. The CFRP shell was set up as 'slave' to both the honeycomb core located within, and the curved honeycomb core, which is attached to it. These honeycomb cores were configured to be the 'master' components.The 'Rigid Body' treatment gave the option to effectively 'fix' all six degrees-of-freedom (DOF) of part of the model from the Z-direction (normal to the door). A typical WRC rollcage model was used for the simulation. By taking advantage of the symmetrical cage design, only one side was modelled for the analysis. Also, the performance of the bodyshell/rollcage structure is excluded in the analysis.

6. Simulation results and discussion

Figure 6 represents the velocity profile of the car while impacting into the tree at the determined speed of 14 m/s. During impact the kinetic energy dissipated and absorbed results in a deceleration of the initial velocity. The velocity plot shows the initial speed decreases to 1.83 m/s over a 20 milliseconds (ms) period. The initial kinetic energy of the vehicle at 14m/s was 137.5 kJ. The remaining kinetic energy of the vehicle, calculated from the reduced velocity, after 20 ms was thus 2.344 kJ.

At an intrusion distance of 0.1 m (82% of 0.122 m) the honeycomb starts to compact and eventually act as a solid aluminium plate. Hence, the impact structure absorbed 98.3% of the kinetic energy carried by the vehicle at a velocity of 14 m/s. The force due to side impact is shared between the sill, the door and SIPS installed in it, and the top part of the bodyshell and rollcage. The loads are fed from the energy-absorbing Honeycomb Core into the backing plate and the beam. The nature of the loading means this component is experiencing bending loads. The beam subsequently reacts against the added support bars in order to feed some of the load into the main hoops of the rollcage at the front and middle of the car. The lower part of the backing plate is supported against the door bars and the bottom of the doorframe. This constrains the plate to bend in two planes rather than just one, reducing the maximum deflection seen by any part of the plate.

Figure 7 shows the effect of the impact on the energy absorption honeycomb core. On initial contact with the tree, the core starts compressing and dissipating energy. As the event progresses, the honeycomb continues to compress, and the beam starts to deflect. At 15ms into the simulation the rear edge of the honeycomb core starts to pull towards the tree as the horizontal webs get extended stretch. The outer skin of the door mitigates this effect (not shown). At 20ms the honeycomb has been fully compressed, and the beam has deflected significantly as it takes a large portion of the load. The initial surface in contact with the tree is very small, but increases with an increase of the intrusion distance of the tree. 80-85% of the honeycomb core thickness is compressed before it becomes solid, with the honeycomb core having a maximum thickness of 0.122 m.

The Honeycomb Core becomes fully crushed in a distance of 0.1-0.12 m intrusion, which increases the force acting on the surface interface very rapidly to a maximum of 1503 kN when the skin of the CFRP backing plate, which is supported on the cage 'X' doorbars, subsequently fails. This failure causes the force to drop significantly, because the backing plate is no longer supported on the CFRP, but on the honeycomb core inside the backing plate. This flat plate of honeycomb core is now fully crushed against the rollcage. The compression of this honeycomb core, and the failure of the CFRP backing plate and beam, absorbs the rest of the kinetic energy. Figure 8 shows that the force acting on the lower support is relatively constant with time, once the honeycomb core is fully loaded (after ~4 ms). This is desirable, since it shows that the component is adequately supporting the honeycomb core, allowing the required crush characteristics to occur.

The energy absorption showed a linear relationship over the whole intrusion distance of the tree is beneficial in keeping the G-loads acting on the occupants as low as possible. At ~7 ms the aluminium honeycomb core tends towards a 'solid plate', causing the applied load to increase, over a reduced displacement. This causes the G-loading to increase to over 100g at the peak deceleration, at ~10ms. However, this high value is only seen instantaneously, therefore below the maximum limit of human endurance. Support Plate fails as a result of this high loading, dissipating energy and so reducing the G-loads experienced. For the remainder of the time period, the deceleration remains fairly constant. Although average attained G-load (~62g) is relatively high as compared to, for instance, Federal Motor Vehicle Safety Standard 208 (2007)(U.S. DEPARTMENT OF TRANSPORTATION,) and also by Melvin (2002)(Melvin and Foster, 2002), it is well below typical G-loads (over 100g) experienced in other races such as in Indy Car crashes. Given that this occurs over a time period of only 20 ms, it is expected that the occupants would be able to survive the loading. However, our futuristic goal is to reduce the G-loads further since lateral G-loads (pulling outward against the force of direction) have been found to have a significant effect on the drivers' muscles such as the neck and head. Lateral G-loads may also have a contributing effect to drivers' consciousness resolving to dizziness as Voshell (Voshell 2004) previously observed in CART race at Texas Motor Speedway.

7. Conclusions

A design concept consisting of a fibre-reinforced outer skin, an energy absorbing aluminium honeycomb core, and two sandwich composites, a support beam and a support plate has been proposed as a side impact protective system for WRC cars. Through simulated results, the system was found to be capable of absorbing and dissipating 98.3% of 14 m/s impact energy into a 0.2 m diameter cylinder, representative of a tree.

The G-loads generated during the side impact are relatively high and are expected to approach human limitations as observed by Voshell (Voshell 2004). This is attributed to the short distance and period over which the energy has to be absorbed. As such, a compromise has been made between the amount of energy, which is absorbed by the structure, and the subsequent magnitude of G-loading applied to the vehicles occupants. However, the authors acknowledge that the use of valid human body computer model representation and the appropriate restraint system model representation is required to effectively address the effect of the side-impact on the occupants.

Lack of specific research into the human tolerance of lateral accelerations during side impacts is highlighted in the paper. Being early studies in an on going research in design and development of SIPS for World Rally Cars, alternative potential designs including further findings will be communicated in follow-up works.

Dr. James Njuguna holds a PhD in Aeronautical Engineering from City University, London. He is also the Course Director for a world class MSc in Motorsport Engineering and Management at Cranfield University. He previously worked as an aircraft engineer for nearly 5yrs specialising in airframes before embarking on a research career. He holds over 10yrs research experience on lightweight structures and structure-property relationship covering a variety of numerical, simulation and experimental research activities. Dr. Njuguna is a recipient of internationally and nationally recognized awards including prestigious Research Council UK Academic

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Caption of Figures

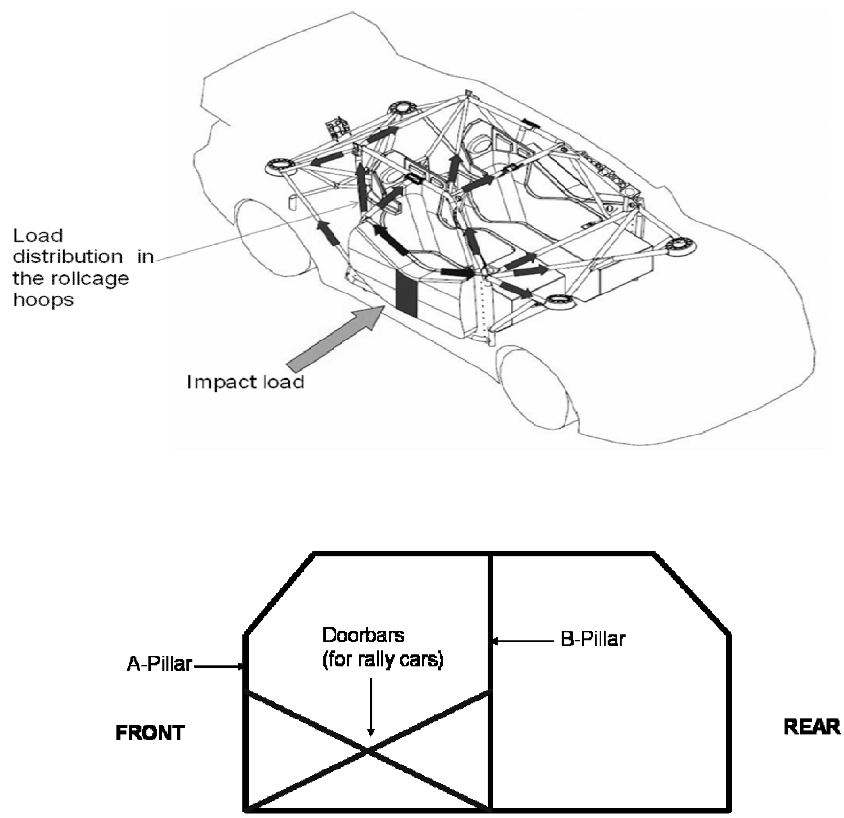

Figure 1 A schematic representation load pathways due to side impact loading (top) and typical WRC rollcage side structure with the ‘x’ type door bars.

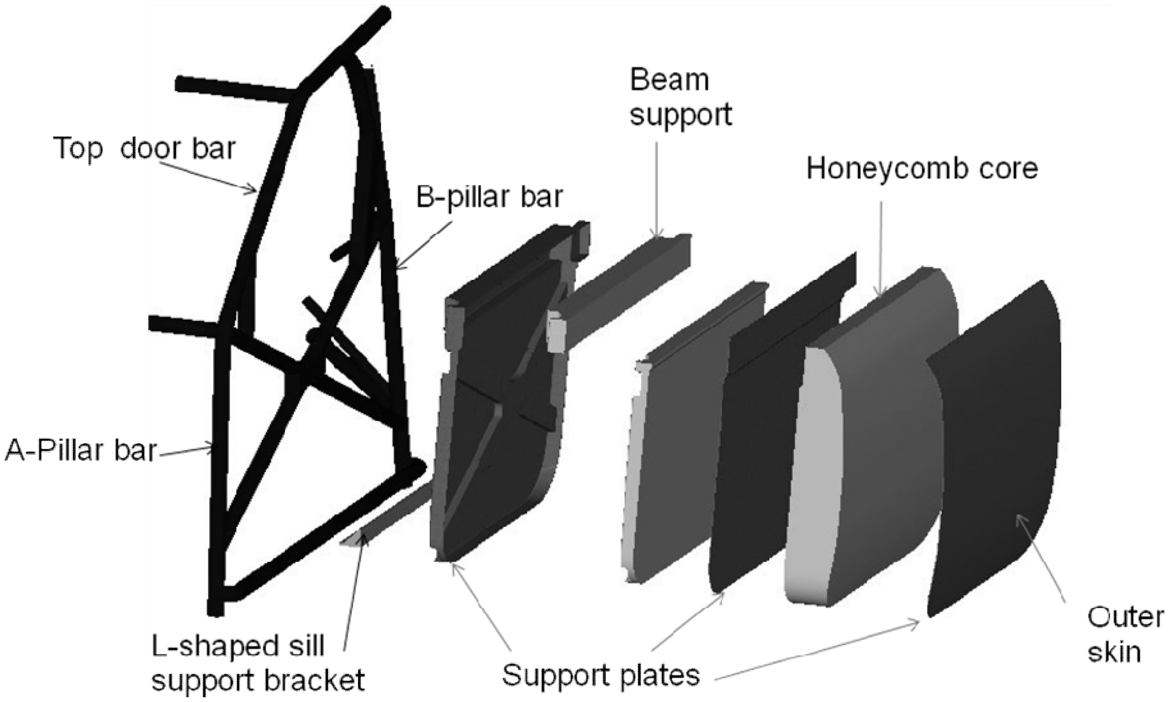

Figure 2 The components of the proposed design

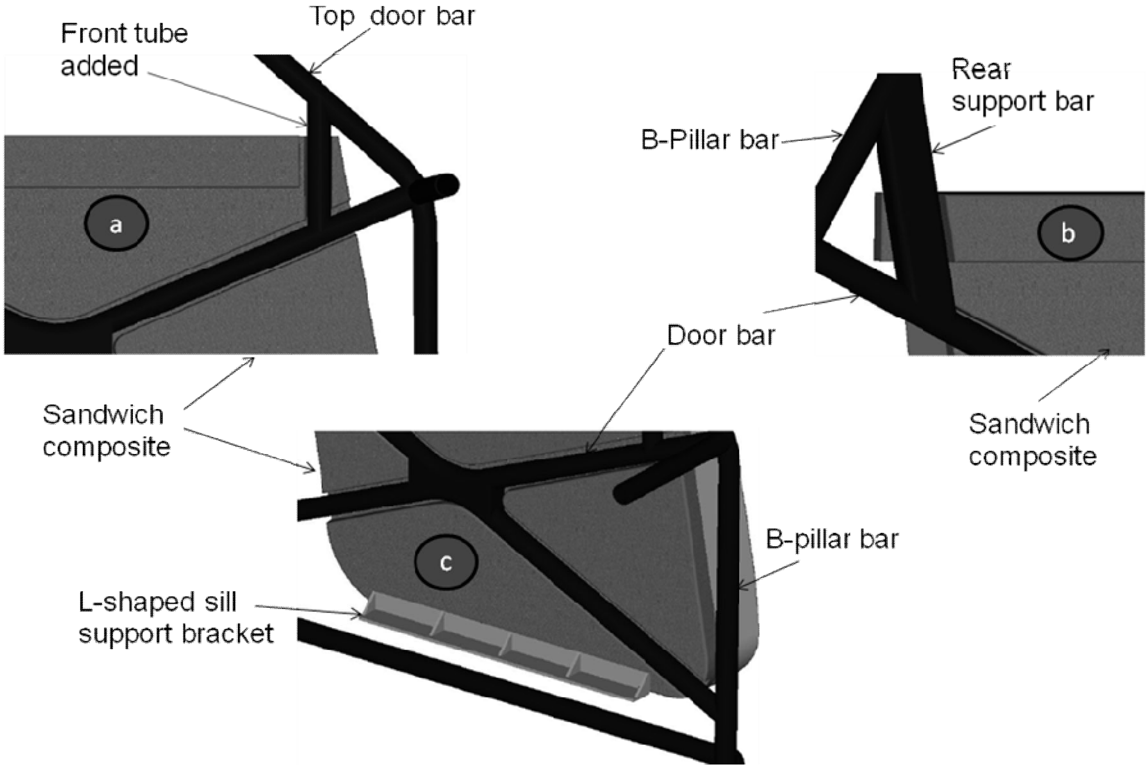

Figure 3 (a) The added front tube between the A-pillar tube and the top Door-bar this tube is welded with its longitudinal axis perpendicular to the floor of the car; (b) weld connection of the rear support bar, welded between the vertical bar behind the B-pillar and the top side-impact bar, right behind the B-pillar. This provides support for the rear of the beam; (c) sill support - the bottom of the plate needs to be supported so that it can react the loads applied to it. An L-shaped support is welded onto the sill to provide the support area. As can be seen in the support is triangulated to provide the appropriate support.

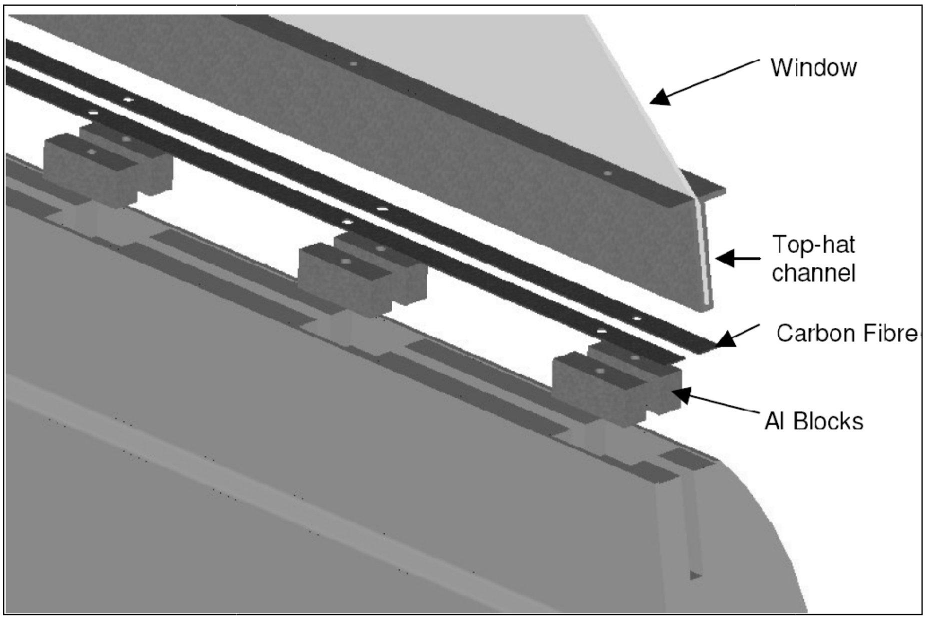

Figure 4 Window support rail

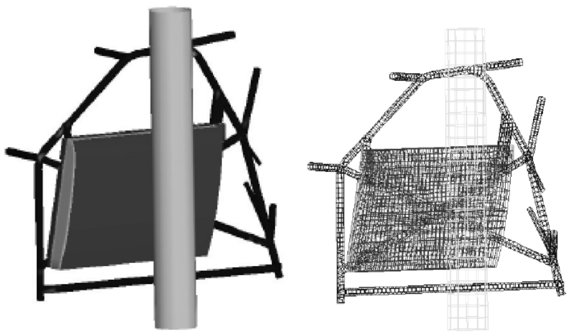

Figure 5 Solid 3D I-DEAS Model and the mesh containing 8000 elements (8-noded brick and 4-noded shell elements) used for simulations

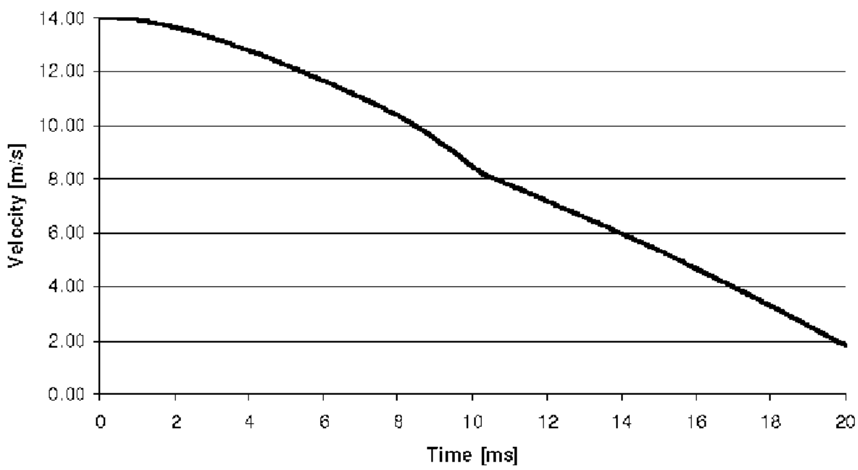

Figure 6 Velocity profile vs time plot

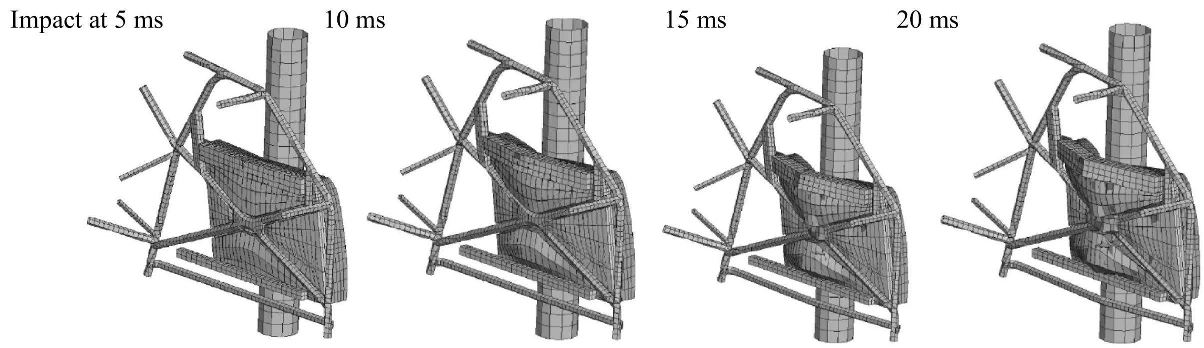

Figure 7 The effect of the side impact on the energy absorption honeycomb core in 5, 10, 15 and 20 ms.

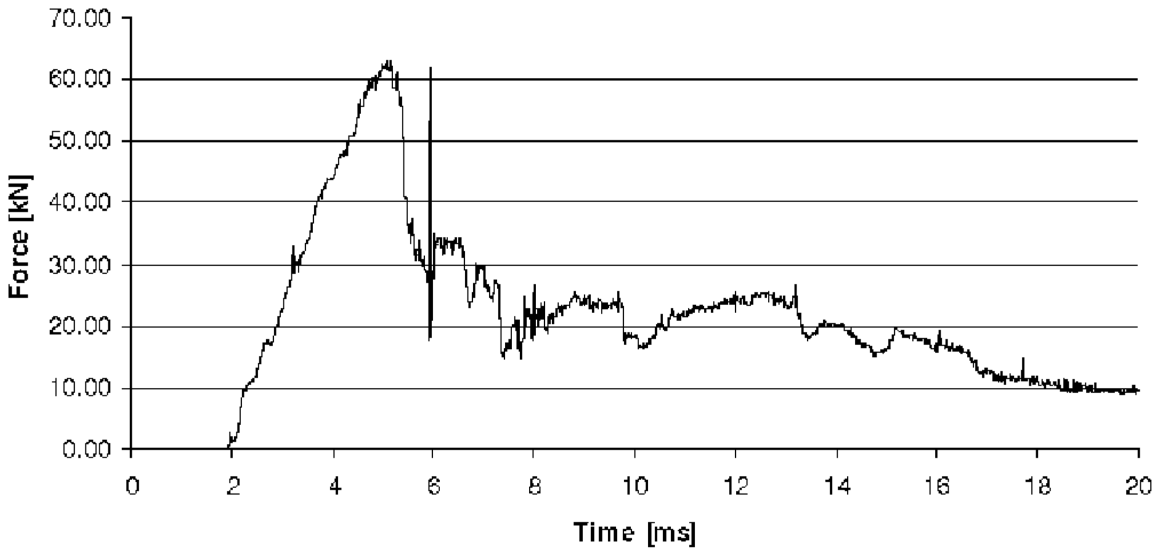

Figure 8 Reaction force acting on the vertical support